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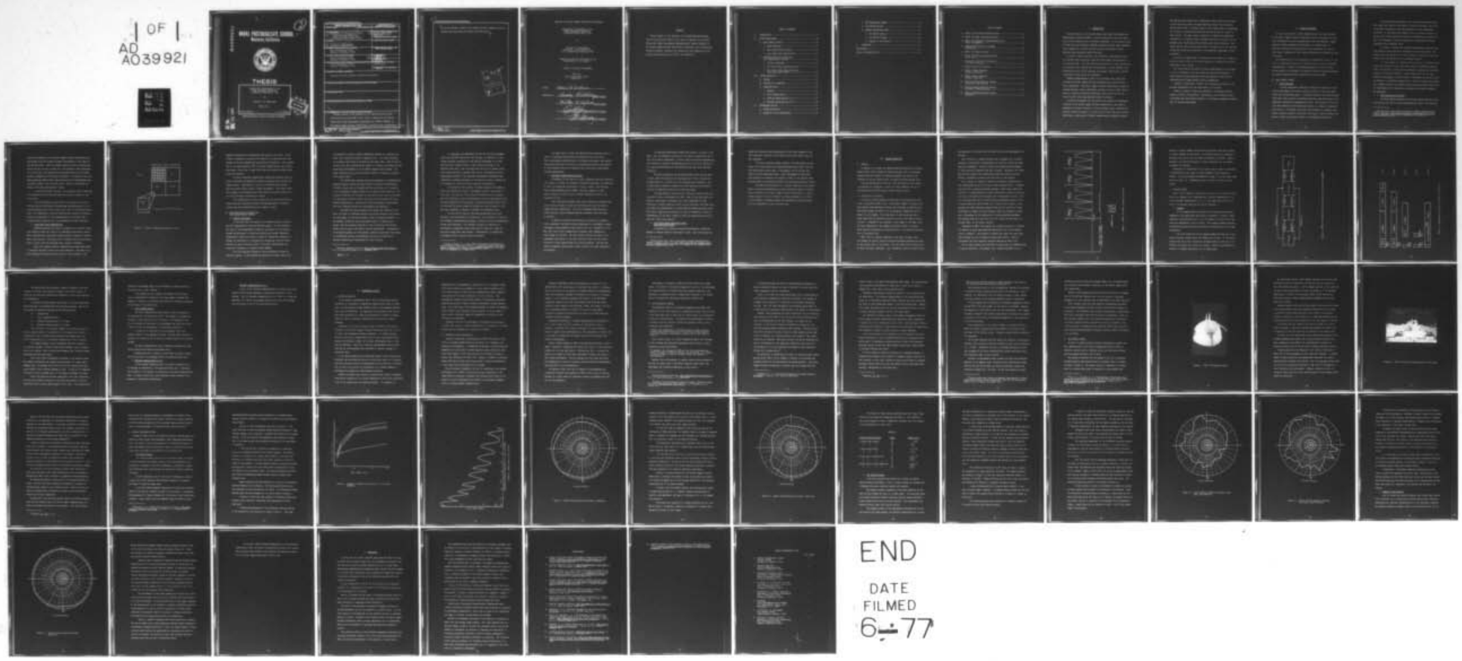

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Monterey, California

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THESIS

INTRODUCTORY INVESTIGATION OF THE
RANGE MEASURING SYSTEM/DATA
COLLECTION SYSTEM (RMS-2/ DCS)

by

William F. H. Berthiaume

March 1977

Thesis Advisor: C. H. Rothauge

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Introductory Investigation of the Range Measuring System/Data Collection System (RMS-2/ DCS)

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Various aspects of the operation of the Range Measuring System/ Data Collection System (RMS-2/ DCS), which is employed by the United States Army Combat Developments Experimentation Command (USACDEC) at the Hunter Liggett Military Reservation, California, were investigated. System development, operation and reliability were summarized and two problem areas associated with RMS-2/ DCS identified.

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I. INTRODUCTION

The basic mission of the United States Army Combat Developments Experimentation Command (USACDEC) is that of operational test and evaluation of both current and future warfare techniques. As the central point for Army test and evaluation, USACDEC regularly performs field experimentation designed to evaluate tactical doctrine and weapons systems employed under simulated combat conditions.

In order to fulfill specific test objectives, experimentation must be conducted under controlled conditions which permit the gathering of all relevant data. The final analysis and validity of field experimentation results, thus, depends upon the adherence to a well designed test methodology as well as the accurate and reliable collection of various categories of data during the experiment.

USACDEC, headquartered at Fort Ord, California, has, since 1956, utilized the Hunter Liggett Military Reservation as a site for many field experiments. The Hunter Liggett Military Reservation, located in southern Monterey County, California, provides an area of some 166,000 acres in a sparsely inhabited environment which may be used as the scene for tests involving simulated combat conditions.

A critical requirement for the control and analysis of experiments conducted at the Hunter Liggett Military Reservation is the need to determine the precise location of various infantry units, vehicles and aircraft during all phases of a field trial in which they are involved. Additionally, some means of rapidly communicating information between

the exercise participants and a centralized control facility must exist. To meet these dual needs the Range Measuring System/ Data Collection System (RMS-2/ DCS) is currently used as the primary means of determining the location of selected personnel and vehicles during the conduct of field trials. The same system is employed to communicate significant information, in a digital format, between those units involved in an experiment and a centralized data collection and control facility. This single system, then, must be relied upon to furnish much of the data and information which will contribute to the analytical assessment of each experiment.

As part of a larger study, the purpose of this thesis is to begin an analysis of RMS-2/ DCS with the final objective of improving the overall performance of the system.

As a first step in the effort to effect improvements to this system it will be necessary to set the problem in historical perspective. A brief history of past techniques which were applied in the position determination and communications field is summarized.

Secondly, a description of RMS-2/ DCS, including the nature of the problems experienced with the installation, is outlined.

Finally, a series of tests was conducted to investigate certain aspects of RMS-2/ DCS operation. Specifically, two potential sources of problems have been further defined: (a) multipath propagation effects, and, (b) antenna performance.

II. SYSTEM DEVELOPMENT

In the 21 year period in which experimentation has been performed at the Hunter Liggett Military Reservation various techniques for position determination and data communications have been employed. Beginning with simple approaches which relied, to a large extent, on physical references for fixing position and transmission of data by voice radio, progressively more complex equipments and systems have been instituted.

The sophistication of each approach was necessarily dictated by the level of technology existent at a particular time as well as budgetary considerations. However, the experience gained in the use of each system guided the development of subsequent follow-on systems including the present Range Measuring System/ Data Collection System.

A. EARLY MANUAL SYSTEMS

1. Chart Reference

In early experiments conducted by USACDEC the approach to meeting the requirement for accurate position location of units was based solely upon conventional means. A standard universal transverse Mercator (UTM) area chart served as a reference from which each participant in an experiment estimated his geographic position. The accuracy of the location data obtained by this method was subject to a number of unpredictable factors. For example, the number and proximity of prominent landmarks, existing visibility conditions and a host of other variables combined to render any position subject to considerable random error.

The participant's familiarity with a particular exercise area, which might have improved the degree of accuracy obtainable, was found to introduce unacceptable biasing influences into the experimental situation. If one player were familiar with the terrain, he would, on the one hand, achieve greater accuracy in estimating his position; however, his knowledge of the area constituted an undesirable tactical advantage over an opposing force.

In order to overcome this problem, experimental design was such that repeated trials were never conducted over the same ground. The exercise area was divided into a finite number of sectors and each subsequent trial was carried out in a different sector.[1]

A system capable of accurate position location of exercise units under such conditions would, then, serve several fundamental purposes. First, the validity of data would be improved by removing the subjective element of individual estimate. Second, familiarity with the area, which was encouraged to aid the soldier in recording his position, would be removed as a potential biasing factor. Lastly, although not realized for a number of years, an automatic system would free participants from the cumbersome task of taking and recording position data throughout the experiment.

2. Area Identification System

The first measure adopted to attain more precise position location data was the use of an area identification system. The territory

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[1] United States Army Combat Developments Command Experimentation Command, History of Field Experimentation Methodology in the United States Army 1956 - 1970, by J. L. Romjue, p. 18, June 1971.

within the boundaries of the Hunter Liggett Military Reservation was partitioned into one kilometer squares corresponding to the grids on the UTM area chart. Each 1,000 meter square was given an identifying number and was, in turn, divided into four quadrants, each designated by a color code. The quadrant was then subdivided into 25 100 meter squares, designated by the letters A through Y. The center of the 100 meter square was marked with a post which bore the corresponding identification number, color code and letter. Figure 1 illustrates the design of the area identification system.

In order to estimate position, the individual read the markings on the nearest post and then estimated his position relative to the marker post.

Such a rudimentary system improved the accuracy of position location data but the burden of maintaining the marking posts, in an area encompassing over 100,000 acres, was a task of considerable magnitude. More importantly, the area identification system did nothing to relieve the participant of the responsibility for continual data recording which interfered with the performance of other functions.

3. Voice Radio Data Communications

Communicating data and control information to a central collection facility during the course of an experiment constituted a second major function which, along with accurate position location of participants, was required. The initial use of standard tactical voice radio sets to fulfill this need suffered from a number of problems.

Under the original exercise communications system, each squad of personnel included a team of two radio operators. One served as a data transmission operator and the other as a data recorder. Two

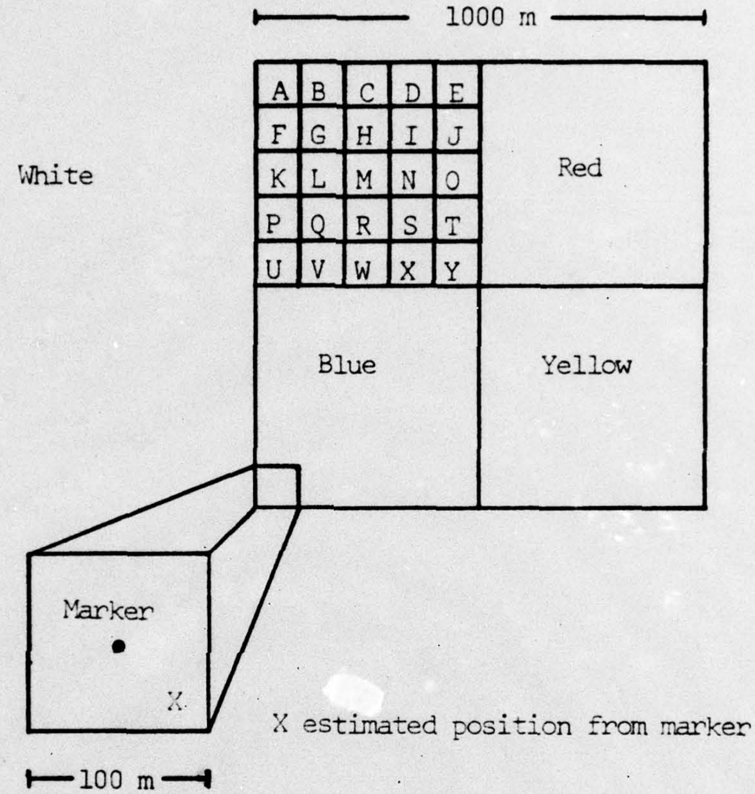

Figure 1. Detail of Area Identification System.

separate frequencies for transmission and reception were used. As the volume of information increased in an exercise, a saturation point was reached on both the transmitting and receiving frequencies. Also, operating at very high frequency (VHF) a reliable communications path existed only where a clear line of sight (LOS) path was available between transmitter and receiver.

In 1959 an advanced communication system was installed which included a microwave retransmission station to improve area coverage over rugged terrain. Additionally, a total of 300 Motorola VHF tactical radio sets were acquired under a single procurement. Five mobile radio vans, capable of performing radio relay functions served as backups for the fixed microwave retransmission station.

This communication system, coupled with the area identification system previously described, served as the primary means of position location and data communications for a number of years.

B. AUTOMATIC POSITION LOCATION AND DATA COMMUNICATIONS SYSTEMS

1. Concept Development

In the late 1950's the need for an automatic position location and data communications system became more urgent. As the complexity and scope of field experiments increased, the ability of the existing systems and personnel to collect and process data became inadequate. Consequently, during this period a number of studies were conducted to examine the feasibility of developing and installing a position determination and data collection system. From these investigations two alternative proposals of a general nature emerged.

The first approach proposed an inverse hyperbolic system for position location. By this method the position of a mobile unit would

be determined by using a single transmitter, mounted on a vehicle, and three fixed receivers located at separate sites. The signal broadcast by the mobile unit would be received at the three sites. Each of the receivers would then rebroadcast the signal to a central processing facility where phase measurements of the different signals would be made. The phase differences then would be used as a basis for fixing the location of the mobile unit.[2]

The second basic approach which was considered for implementation employed digital reports and signal bursts for position determination. A digital signal would be transmitted from the mobile unit in response to an interrogation signal initiated by a central control facility. Individual addresses, one allocated to each mobile unit, would be transmitted sequentially from the control facility with time allowed for reply between transmissions. Position would then be measured by determining the time difference between the interrogation and response.[3]

Although both these proposals were technically feasible at the time, the first, or hyperbolic method of position location, was favored for what appear to have been economic as well as technical reasons. It was assumed, during the early development phase of creating such a system, that the existing inventory of some 300 Motorola VHF tactical radios could be used as the mobile vehicle transmitters. Incorporation of existing equipment into the position location system would then result in considerable savings by eliminating the need to procure new or specially manufactured transceivers for this function.

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[2]Stanford Research Institute, <u>CDEC Instrumentation Study Phase I</u>, by J. H. Jones and others, p. 27, <u>December 1959</u>.

[3]<u>Ibid</u>., p. 47.

In principle, the employment of this off the shelf equipment would have provided substantial cost savings, the adherence to this concept probably contributed to the delayed development of an automatic position location system. After extensive testing of the Motorola radio sets it was concluded that they did not possess sufficient phase stability to warrant their use in the proposed position determination system.[4] Also previous investigation determined that commercially available equipment in the position location category was not adequate for field use without extensive modification.

The failure of the approach of making piecemeal procurements, which had directed the course of development efforts, was evident in this case. The need for a well defined development and procurement plan for acquiring a position determination and data communications system was recognized by the procedure of acquiring equipment which could be modified from proven commercial designs had been successful in the past and, therefore, continued to dominate the planning process.

In late 1962 an initial long range development plan, which focused on the justification and funding for the purchase of a functionally designed instrumentation package, including a position determination system, was formulated. This document stressed the importance of developing an integrated system which would be tailored to meet the particular needs which then existed. Unfortunately, no significant development efforts resulted from its issuance.

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[4] Research Office, U. S. Army Combat Developments Experimentation Command Research Memorandum RO-RM 21, A Laboratory Study of VHF Field Radios as Elements of a Position Determination System, by L. O. Lane and J. R. Woodbury, p. 3, April 1962.

Two years later, in 1964, new administrative practices with respect to fulfilling instrumentation requirements were instituted. Strict performance specifications for systems and equipment were adopted and greater attention was devoted to reviewing modification requirements so that hardware would not be acquired until satisfactory performance had been demonstrated.

2. The Direct Range Measuring System

In response to the need for a fully integrated position determination system, a contract was awarded to National Electronics, Incorporated, in 1963, for design and installation of such a system. The resulting Direct Range Measuring System (DRMS), initially composed of eight master stations (A stations) and 99 mobile responders (B units), was delivered in 1964.

The A unit master stations were fully contained in portable vans which could be located to cover any specified area within the Hunter Liggett Military Reservation. The B unit responders were mounted on either vehicles, such as armored personnel carriers, tanks and jeeps or aircraft.

In order to calculate the position of a mobile unit equipped with a responder, the master station transmitted an interrogation signal, including a unique address for each mobile unit, at a frequency of 1118 MHz. The B unit, after recognizing its address, then transmitted a reply signal at 1058 MHz. The time interval between initiation of interrogation and receipt of the reply from the B unit was then translated into a slant range between the A and B stations. This data was stored on magnetic tape devices at each A station for later correlation and analysis.

By combining simultaneous ranges from several A stations to the same B unit the geographic position of the vehicle equipped with the B unit could then be determined. As each A station operated independently, the procedure of actually determining position could not be carried out on a near real-time basis but was performed some time after data was collected.

The Data Acquisition and Recording System, which was installed in 1966, added the capability of accepting data at the A station and transmitting it to a central site for recording and correlation. The following year a manpack responder unit which permitted the automatic location of individual troops in the field was added.

Although generally successful as a prototype system, plans were initiated to seek a replacement for DRMS. Some of the individual components, particularly the manpack unit, were cumbersome in field operations. Another important factor was the conclusion that DRMS would not permit the determination of intervisibility between opposing forces. This latter capability was required in order to determine, by means of instrumentation, the exact instant at which two opposing ground forces came into view of one another.[5]

3. The Current Range Measuring System/ Data Collection System

A contract for a follow-on position determination system was awarded to General Dynamics Corporation in 1966. Some difficulties in

[5] United States Army Combat Developments Command Experimentation Command, History of the U. S. Army Combat Developments Command Experimentation Command 1965 - 1969, by J. L. Romjue, p. 99, December 1970.

design and production were experienced but the first elements of the new system were delivered in mid 1968 and the entire system later put into operation.

The fully installed system, referred to as RMS-2/DDS, was composed of the second generation Range Measuring System (RMS-2) and the Data Distribution System (DDS), a replacement for the earlier Data Acquisition and Recording System. Later redesignated as RMS-2/DCS, the principles of operation are similar to those of the previous DRMS although nearly all associated hardware and operating parameters differ.

The RMS-2/DCS installation is currently employed as the primary means of position determination and data collection support of experiments conducted at the Hunter Liggett Military Reservation. A second system, similar to that of USACDEC, has been purchased by the Office of the Director of Defense Research and Engineering (Test and Evaluation) for employment in joint service tests.

III. SYSTEM DESCRIPTION

A. PURPOSE

As implied by its name, the Range Measuring System/Data Collection System (RMS-2/ DCS) performs two basic functions: that of providing accurate position location of selected personnel and vehicles and enabling the two way communication of simple pro-forma message data.

Such information may be used on a real time basis for the control of experiments in progress or stored for later reference for use in reconstructing the events which occurred during a trial.

B. PRINCIPLES OF OPERATION

In order to obtain accurate location data a *multilateration* technique is employed by RMS-2/ DCS. Simultaneous ranges to a mobile unit from several fixed reference stations are calculated by measuring the time delay between the start of an interrogation command and the response to this command. This time delay is then translated into a slant range from the reference station (A unit) to the mobile station (B unit). A maximum of ten different A unit ranges to the same B unit are then transmitted to the command and control center (C station) where they are correlated by a central processor to calculate the position of the mobile unit.

RMS-2/ DCS is a network composed of four types of basic units. Two command and control stations contain processing equipment and serve as the central nodes of the system. They are fixed site locations both of which are nearly identical. One is generally used for system control

and operation (C-2 station) and the other for test and maintenance (C-1 station).

The C station is a manned facility and is equipped with a central processor, line printer, storage media, X-Y position plotter and other associated equipment. Position location and communications messages to field units all originate from the C station. Similarly, all incoming position location and communications data are received by the C station, converted to parallel form and input to the computer.

The C station is linked to vehicles or personnel equipped with B unit transponders by one of two basic radio frequency paths. Transmission from the C station may proceed through a fixed relay station (D station) to a semi-permanently located interrogator station (A station) and then to the mobile unit equipped with a transponder (B unit). The C to D station link may be omitted from the transmission path if line of sight conditions exist between the C station and A station. Thus, although the radio frequency emission from each of the units is omnidirectional in nature, the path actually taken by a message is unique and is determined by the combination of routing addresses assigned. The response from the B unit will, in turn, follow the same path, in reverse order, to the control station.

Components of RMS-2/ DCS operate at a carrier frequency of 918 MHz. The carrier is pulse code amplitude modulated by one of four subcarriers or channels. Each channel is divided into upper and lower sidebands through the use of selective narrow band filters. Figure 2 illustrates the radio frequency spectrum employed by RMS-2/ DCS.

Two of these channels are allocated to each device for communications in a given direction. For example, the C station transmits to an A

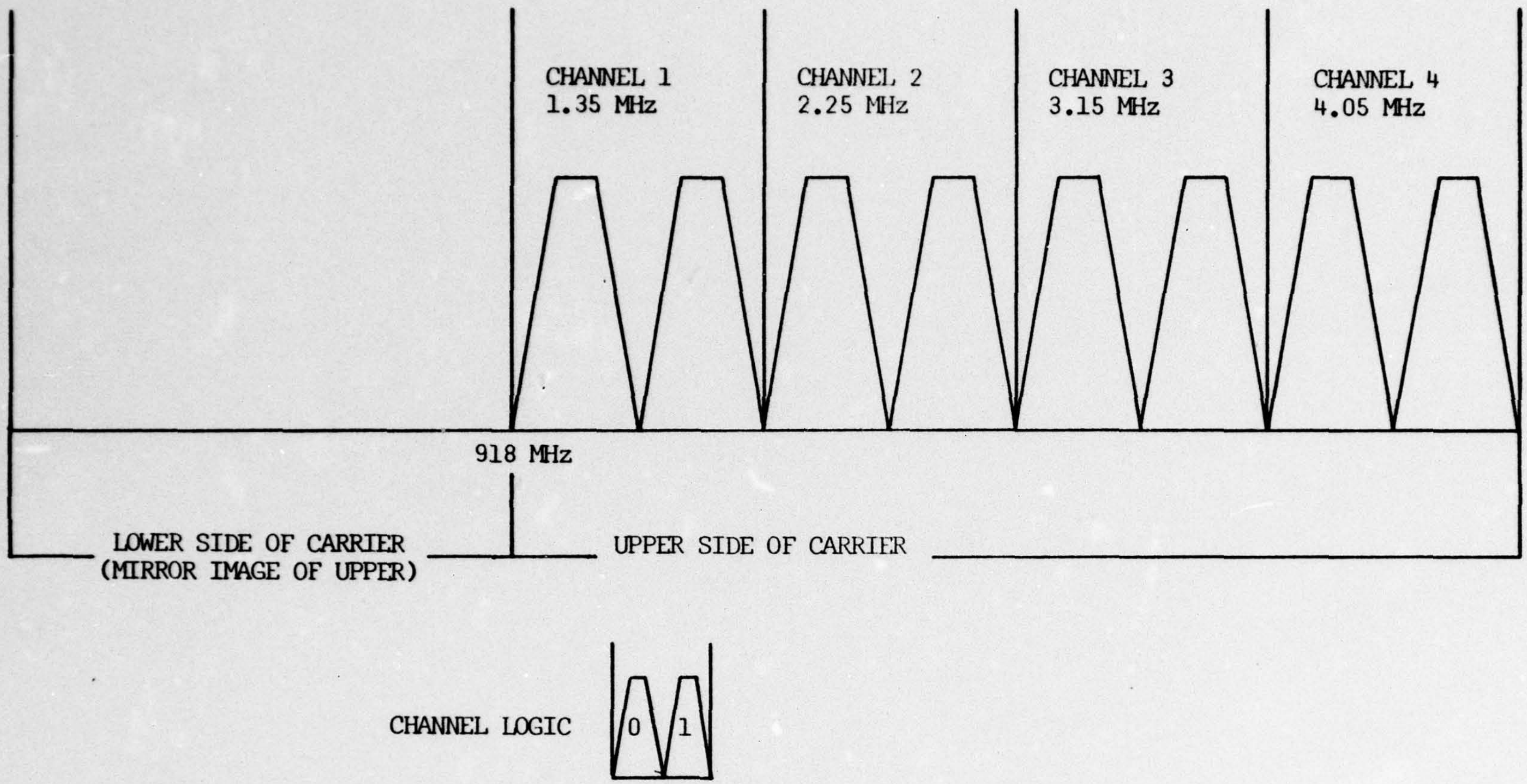

Figure 2. RMS-2/ DCS Radio Frequency Spectrum.

station on channel numbers one and four and receives from the A station on channel numbers two and three. An initializing pulse is employed to determine the type of unit for which the message is intended. Figure 3 describes the interrelationships of system components and the channel assignment allocations.

Information is transformed into a binary code by means of alternately transmitting on the upper or lower sidebands of the respective channel. The lower sideband corresponds to logic "0" and the upper sideband to a logic "1". Transmission rate is fixed at 200,000 bits per second.

C. OPERATING MODES

RMS-2/ DCS is capable of operating in any one of four discrete modes. These are: ranging, short communications, extended communications A to B and, extended communications B to A. A two digit data field in the text of the message specifies the mode of operation.

1. Ranging

In the ranging mode of operation the A station which has been addressed in the appropriate data field is requested to obtain a range reading to the selected B unit. A 23 bit command is output by the computer and transmitted to the C station. This ranging command specifies the particular path that will be followed in obtaining the A to B range information.

The first three bits of the ranging command indicate one of the three D stations through which the command will be sent. If the transmission path omits the D station and proceeds direction from the C to A station, this field will contain all zeroes. Figure 4 illustrates the sequence of message transmission in the ranging mode.

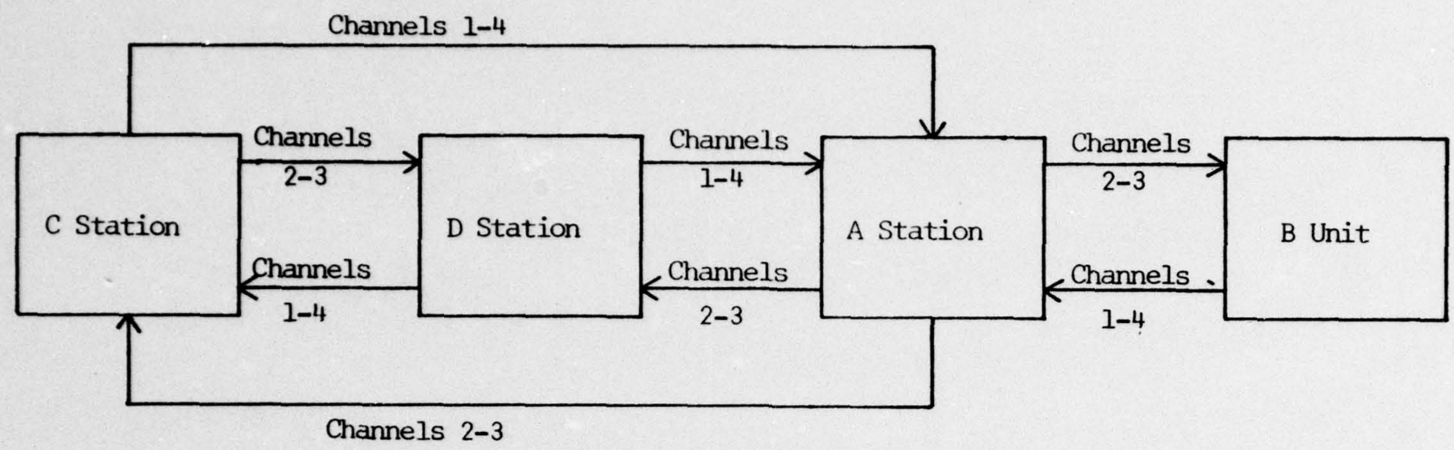

Figure 3. RMS-2/ DCS Component Interrelationship and Channel Assignments.

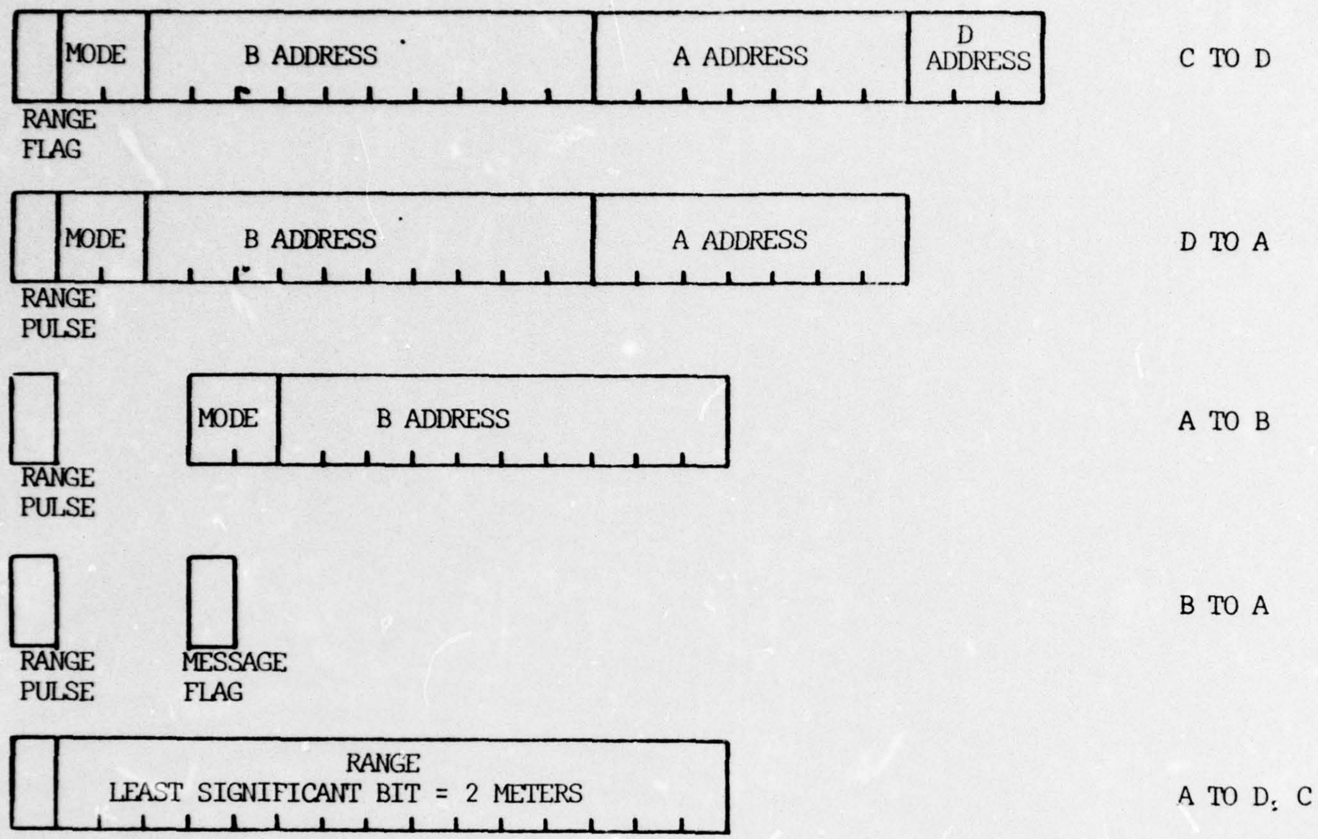

Figure 4. Ranging Mode Sequence of Message Transmission.

The second data field contains a seven bit address of the particular A unit which will obtain the range to the mobile B unit. A third ten bit data field specifies the identity of the B unit which will be interrogated.

Following the three address data fields is a two bit mode field which indicates the operating mode that has been selected. One of the four modes are specified according to the following code:

00	Ranging Mode
11	Short Communicates Mode
10	Extended Communications A to B Mode
01	Extended Communications B to A Mode

The last digit in the ranging command is a range flag which is used to specify either a 9 kilometer or a 64 kilometer wait period to be observed by the A station after initiating the ranging pulse and before transmission of a "no response" message back to the C station.

The ranging command is then transmitted from the C station to a D station (optional if line of sight exists between C and A stations) hen to an A station. The A station then transmits the B station address, operating mode and range pulse.

The B unit, after recognizing its address in the received ranging command, retransmits the ranging pulse followed by a single digit message flag. The message flag is set by the B unit operator and indicates whether he has a special message to send. A value of "1" signifies the desire to send a message and a "0" indicates no message to be sent.

After receiving the returned range pulse, the A unit translates the time delay between initiation of the pulse and receipt of the retransmission into a slant range between the two units. This range value,

along with the message flag, is then returned, in reverse order via the same route to the C station.

Upon receipt by the C station, the range value from the A unit is combined with a minimum of two other ranges, obtained from separate A stations, to calculate the position, in latitude, longitude and elevation of the mobile unit.

2. Short Communications

The short communications mode permits a four bit message to be transmitted to the specified B unit. The message is displayed on an array of four lights on the B unit module. The meaning of this four bit message is determined by a prearranged code which may be developed to meet the requirements of a particular operation.

In addition to receiving a four bit message, the B unit operator sends a 13 bit message in return. The path that the return message will follow will be the same, in reverse order, as the original message.

The short communications mode is generally utilized only with troops equipped with manpack transponder units.

Message structure is similar to that shown in Figure 4 except that the four and 13 bit messages follow the operating mode field.

3. Extended Communications A to B

In the extended communications A to B mode of operation a 42 bit message is transmitted to the specified mobile unit. The mobile unit operator is not required to respond as in the short communications mode. A single validity bit, which indicates correct receipt of the message, is transmitted automatically.

4. Extended Communications B to A

Lastly, in the extended communications B to A mode, the B unit operator who has been addressed is requested to transmit a 42 bit message. Both the extended communications A to B and B to A modes are generally used with B unit equipped vehicles only, due to the larger size and weight of the 42 bit input/output device.

IV. PERFORMANCE FACTORS

A. SYSTEM RELIABILITY

In its present configuration RMS-2/ DCS has occasionally proven inaccurate or unreliable in ranging and communications modes of operation. In most cases no single specific cause of the degraded performance could be determined. The magnitude of the problem itself has not been well defined but, at times, has precluded the conduct of experiments for lack of sufficient communications and position location coverage.

Operating at Ultra High Frequency (UHF), the RMS-2/ DCS network installed at the Hunter Liggett Military Reservation must rely on line of sight (LOS) propagation between components. To obtain accurate position location and communications data a clear unobstructed transmission path between a number of A station interrogators and a B unit must be available. Since the A units are semi-permanent installations they may be, and frequently are, relocated to improve coverage of a particular area.

If all system components are operating properly within design specifications then selecting the sites of a sufficient number of A stations, such that each may achieve LOS transmission to and from both a D station and a B unit, should ensure the availability of a network capable of performing the ranging and communications functions.

Numerous instances have, however, occurred where, given the apparent satisfactory condition of all system components as well as LOS conditions, links in the network have not operated properly. For example, in

preparation for an experiment in January 1977, two A stations, which were located within one kilometer of a test vehicle equipped with a B unit were unable to effect two way communications along a significant portion of the route travelled by the test vehicle. Such problems are recurrent and are the source of considerable additional measures which must be taken to achieve satisfactory system performance. As in this case, it may become necessary to conduct an extensive check of RMS-2/ DCS coverage in each area prior to an experiment to ensure that a sufficient number of independent A station to B unit data paths are available.

Currently, there is no sure manner of predicting the occurrence of RMS-2/ DCS outages. Overall reliability of the system is, at times, erratic and not traceable to a known set of factors.

B. APPROACH OF THE INVESTIGATION

Ideally, the problem of determining why RMS-2/ DCS does not function in a reliable manner should be the object of a systematic and exhaustive investigation. A comprehensive analysis, involving detailed examination of each facet of system operation under controlled conditions would appear to offer the best hope of providing the means to improve the reliability of RMS-2/ DCS. However, a number of considerations which must be taken into account serve to limit the feasibility of any large scale investigation of the system.

From an economic standpoint, the cost of conducting a full system performance test of RMS-2/ DCS would prove cost prohibitive. The large number of personnel, equipment and resources which would be required in such an undertaking would exceed the acceptable budgetary limits of current USACDEC funding levels.

Secondly, RMS/SCORE, which was developed as a follow-on to the USACDEC RMS-2/ DCS installation, is currently the object of a rigorous test by the Office of the Director of Defense Research and Engineering (Test and Evaluation) designed to determine the accuracy of the newer system. It is, therefore, possible that results of the RMS/SCORE evaluation, begun in late 1976, will provide data which may define sources of error common to both systems. Hence, the conduct of a full scale performance analysis of RMS-2/ DCS would, in some cases, potentially duplicate the objectives and tests of the RMS/SCORE performance evaluation program.

Operational scheduling of USACDEC experimentation requirements is also a factor which must be considered in formulating a plan of analysis. The RMS-2/ DCS system is dedicated on a first priority basis to support field experimentation. The availability of RMS-2/ DCS for purposes of conducting performance tests would be minimal under current circumstances.

Lastly, certain aspects of RMS-2/ DCS have been previously investigated. Reference 5 summarizes the results of a series of investigations carried out in a one year period. Additionally, Ref. 6 contains the results of a number of field tests performed to analyze the causes of poor system performance. Various problems have also been discovered and documented as a result of lessons learned during field experiments employing RMS-2/ DCS instrumentation.

The approach, then, that will be adopted in investigating and attempting to improve the operation of RMS-2/ DCS is that of detailed analysis of a small number of potential sources of problems which have not yet been resolved.

Accordingly, two aspects of RMS-2/ DCS were chosen for further study: The problem of multipath propagation as well as the performance and characteristics of antennas which are currently employed. Each represents a potential source of significant influence on the overall level of accuracy and reliability achievable by RMS-2/ DCS.

C. THE PROPAGATION PROBLEM

The potential effects of multipath propagation upon RMS-2/ DCS reliability is not well understood or appreciated despite the fact that it was identified some 17 years ago as a major factor in the design of a position location system. In weighing the disadvantages of various alternative position location systems the probable effects of this phenomenon were recognized,

> "Because VHF propagation is essentially line of sight, however, systems using these frequencies will suffer major shadowing and multi-path effects in mountainous terrain such as that found at HLMR." [6]

Some 15 years later, in a report summarizing RMS-2/ DCS problems, it was concluded that multipath propagation was not alone, a major influence on system performance.

> "In general, the coverage (of RMS-2/ DCS) can be explained completely in terms of hardware problems, any multipath, if it exists, is not sufficient to cause no response unless the hardware is contributing."[7]

However, with the exception of several limited tests performed in the last two years, much of the effort directed toward RMS-2/ DCS improvement has minimized examination of this problem.

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[6] Stanford Research Institute, <u>CDEC Instrumentation Study-Phase II</u>, By J. H. Jones and others, p. 11, March 1960.

[7] Braddock, Dunn and McDonald Scientific Support Laboratory Report TSP-0764-75 <u>RMS Evaluation Final Report</u>, T. S. Penfound, p. 50, 30 May 1975.

To briefly describe the nature of the multipath phenomenon in a greatly simplified manner, two basic situations involving radio frequency propagation must be considered.

First, in an ideal free space environment with no intervening objects between a transmission source and a receiver, the strength of a signal at the receiver is a function of the distance separating the two. Thus, the field strength of the received signal varies in a fashion which is inversely proportional to the square of the distance.

However, when considering an actual terrestrial two way communications system, such as RMS-2/ DCS, the set of factors governing reception and transmission are far more complex. No longer can the intensity of the received signal be predicted by knowing only the physical distance between transmitter and receiver. Multiple reflections from the earth's surface as well as other natural and man made objects influence, in a complex fashion, the strength of the signal which will be received. Additional factors such as the operating frequency, polarization of the signal and conductivity and contour of the surface will, in turn, determine the degree to which multipath effects will be experienced.[8]

The difficulty in determining the extent to which multipath propagation affects RMS-2/ DCS is largely a function of the diverse and irregular nature of the area in which the system operates. The Hunter Liggett Military Reservation is located five miles inland from the

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[8]Bachynski, M. P., "Microwave Propagation Over Rough Surfaces," RCA Review, v. 20, no. 2, p. 308-335, June 1959.

Pacific Ocean on the Santa Lucia Mountain coast range. The entire reservation measures approximately 20 miles east to west and 34 miles in length with a total area of about 166,000 acres.

Extremely rough mountain terrain is typical of the northern area of the reservation. The features change greatly as the mountainous area gives way to moderately rough and broken foothills and lower elevations and then, in the southeastern region to flat and rolling land. Vegetation ranges from dense pine, fir and oak in mountains and hills to only a slight covering of grass in much of the lower areas.

The potential or actual effects of multipath propagation within the Hunter Liggett Military Reservation are, therefore, nearly impossible to predict due to the irregularity of the area. While multipath effects resulting from reflection of radio waves in one area might be significant, the situation is likely to differ over only a small distance.

A test was conducted by the Braddock, Dunn and McDonald Scientific Support Laboratory in 1975 to determine the extent of multipath propagation and if it presented a serious problem to RMS-2/ DCS operation. Although results of this test were largely inconclusive, some evidence of multipath effects was noted.[9]

In 1976 a series of tests was carried out by USACDEC personnel to determine fade margins and the effects of marginal signal conditions on the A station - B unit link. Results of these tests pointed to possible multipath effects when the B unit was operated with a high sensitivity setting. Additionally it was noted that,

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[9]Penfound, Op. Cit., p. 28

"Vehicle metal surfaces appear to negate difference nulls due to the antenna pattern and/or ground multipath."[10]

Data gathered as part of this investigation indicate the existence of multipath effects associated with RMS-2/ DCS components. Additionally, the observation that the vehicle surface, in fact, exerts a strong influence on the antenna radiation pattern is supported.

It would appear that the presence of multipath propagation effects on some RMS-2/ DCS links might, at this point, be presumed. However, the magnitude of these effects has not been established. Here, again, the great variance of the terrain would prevent arriving at any general conclusion on the effects of multipath propagation on the reliability of the entire system.

Some appreciation of the possible degree of multipath effects on RMS-2/ DCS might be gained from those studies of land mobile radio performed in the civilian sector. However, several factors complicate this approach.

The 900 MHz frequency band was opened only recently to land mobile operation which had been previously confiend to much lower frequencies (25 - 50 MHz). Therefore, the body of knowledge dealing with multipath propagation for mobile communications systems operating within this frequency range is still limited.

Secondly, non-government mobile systems utilizing this frequency band are of two general types: automatic vehicle monitoring systems (902-912 MHz and 918-928 MHz) and various industrial, medical and scientific systems (902 - 928 MHz). As the vast majority of these

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[10] United States Army Combat Developments Experimentation Command Engineering Services Branch, Memorandum, "RMS A/B Link Attenuation Tests," by P. K. Patel, 23 November 1976.

systems are found in urban and suburban areas, the surrounding physical conditions differ greatly from those of the Hunter Liggett Military Reservation.

However, some reserach which has dealt with the study of propagation of 900 MHz band signals shows that the effects of multipath propagation at this frequency can be significant in an urban setting.[11]

Thus, attempts which have been aimed at establishing the extent of multipath propagation effects on RMS-2/ DCS have been largely inconclusive. The difficulty which would be encountered in quantifying, much less localizing, these effects would be considerable. Based on what has been learned about this problem through tests conducted at the Hunter Liggett Military Reservation as well as research in the civilian sector, an assumption that multipath effects may be significant within certain geographic sub-areas covered by RMS-2/ DCS appears to be justified.

D. THE ANTENNA PROBLEM

In order to obtain position location information and permit two way communications to and from the command and control center (C station), various types of vehicles as well as individual soldiers may be equipped with RMS-2/ DCS B units.

The antenna associated with the manpack B unit is a vertically polarized quarter wave monopole which is normally worn on a helmet as shown in Figure 5. The antenna itself is connected by a coaxial cable to a micro-B unit which is carried in a back mounted pack.

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[11] Cox, D. C. and Leck, R. P., "Distributions of Multipath Delay Spread and Average Excess Delay for 910 MHz Urnan Mobile Radio Paths," IEE Transactions on Antennas and Propagation, v. AP-23, no. 2, March 1975, p. 206-213.

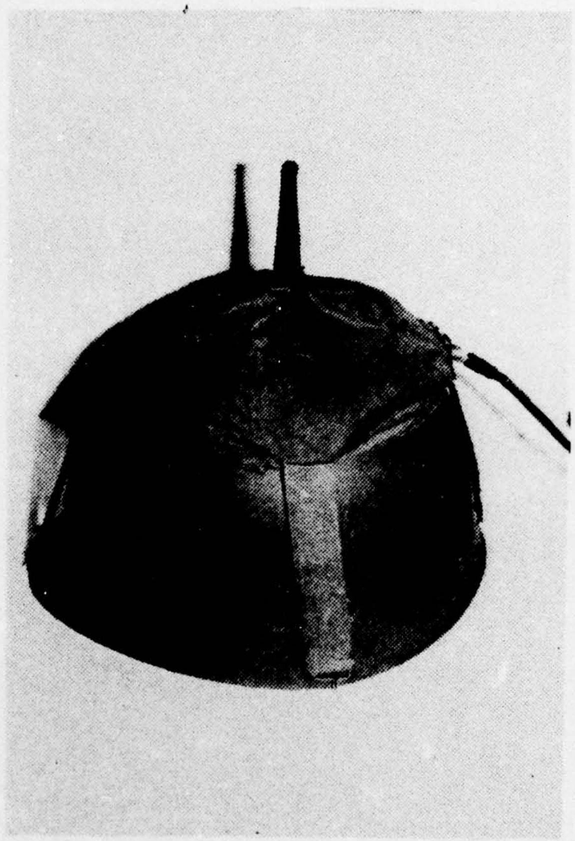

Figure 5. RMS-2/ DCS Helmet Antenna.

An input/output device, which permits operation in the short communications mode, is connected to the micro-B unit and carried on a belt worn around the waist. A set of toggle switches on the input/output device allows the soldier to code and transmit a 13 bit message. Additionally, a series of four display lights on the same device allows the receipt of short communications messages which are sent from the C station.

Antennas employed with the vehicle mounted B unit are of two types. A disc-cone antenna, which was originally manufactured for use with the previous Direct Range Measuring System (DRMS) is occasionally utilized. However, as this antenna is no longer manufactured and the existing inventory has become depleted use of this antenna is limited.

The second, and more commonly used vehicle antenna is a dipole shown in Figure 6. This unit, specifically designed for RMS-2/ DCS, is mounted on a six foot mast which is secured to the vehicle body.

A B unit, a 42 bit input/output device permitting operation in the extended communications modes, and a dipole antenna constitute the major components of the RMS-2/ DCS instrumentation installed on selected vehicles such as the M60 tank or armored personnel carrier.

A major question in the analysis of the overall reliability of RMS-2/ DCS is the performance of both these type antennas. A limited amount of data provided by the manufacturer describes the antenna characteristics obtained from testing. Also the experience gained from the use of the antennas has resulted in some store of information on their reliability and performance. However, relatively little is currently known about the actual characteristics of the antennas under operating conditions.

Figure 6. RMS-2/ DCS Vehicle Antenna Mounted on M60 Tank.

Again, as was the case with the matter describing overall system reliability, the magnitude of difficulties attributable to antenna problems has not been defined. It has been estimated that defective antennas and associated cables account for, perhaps, as much as 25 per cent of the problems experienced in the field by RMS-2/ DCS. In addition substandard antennas have been found to contribute to the marginal operation of other system components.[12]

A number of physical and mechanical problems have been noted with each type of antenna. The connection between the coaxial cable and helmet antenna can be broken under limited stress resulting in damage to and, hence, substandard operation of the antenna. The vehicle antenna, also, is prone to damage from normal field operations. Generally mounted at a high position on the platform vehicle, it often strikes low hanging objects such as free branches resulting in damage.

The question of how these antennas operate under conditions in which they are used is well worth answering as a step in seeking to determine why RMS-2/ DCS is subject to significant recurring errors.

The theoretical manner in which each of the antennas operates is known. Both are vertically polarized and designed to transmit an omnidirectional signal in the horizontal plane. However, the way in which the antennas may be affected by factors such as surrounding objects is not fully understood.

As mentioned in the previous section, since the 900 MHz frequency band has only recently come into use for mobile communications, research on antenna performance is not extensive. The first results

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[12] Penfound, Op. Cit., p. 49.

and outline of a program designed to investigate the effects of the urban multipath environment and vehicle structure on antenna operation at 900 MHz were published in 1975 and present some potentially useful data for explaining RMS-2/ DCS mobile antenna characteristics.[13]

E. ANTENNA PERFORMANCE TESTS

A number of tests of both the helmet and vehicle antennas were conducted in order to gain some knowledge of their operating characteristics. The object of this test program was to determine the manner in which the antennas would be affected by various conditions which simulated those that might be experienced in field operations.

1. The Helmet Antenna

Two helmet antennas were used in the initial stages of testing to perform extensive preliminary checks of test instrumentation and procedures. Throughout these first experiments, consistently significant differences were noted between the antennas in terms of radiation efficiency.

A short comparative test of this pair of antennas, as well as a second pair later received, was therefore carried out to measure the degree of variation among them.

An HP 612A signal generator adjusted for an amplitude modulated signal of 918 MHz was connected to each of the antennas, in succession, and measurements of signal strength for five discrete input levels were recorded. Output signal level was measured using an AN/URM 17 radio

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[13] Davidson, A. L., "Mobile Antenna Gain at 900 MHz," IEEE Transactions on Vehicular Technology, v. VT-24, no. 4, November 1975, p. 54-58.

interference/field intensity meter connected to a standard dipole antenna (AT-255) located at a distance of 10 meters from the transmitting antenna.

Results of these measurements are shown in Figure 7. The least efficient of the four antennas tested exhibited evidence of some external damage to the connector, a problem often noted with the helmet antenna. After the connector had apparently been repaired a second test of the same antenna was performed but resulted in no improvement in operation.

A test was devised to measure the magnitude of difference nulls in the radiation pattern of the helmet antenna. The antenna, mounted on a helmet and at a height above ground of two meters was connected to a signal source (HP 612A) which supplied a 918 MHz AM signal to the antenna. A dipole antenna located on a movable platform was employed to receive the test signal which was measured by using the AN/URM 17 field intensity meter. The receiving antenna was moved away from the transmitting helmet antenna along a straight track reference line.

Signal intensity was then measured as a function of horizontal distance between the two antennas. The resulting difference nulls were prominent in both the near and far fields. The difference between adjacent peak and null averaged 4.5 to 5 db as shown in Figure 8.

A series of trials was then conducted to evaluate antenna performance under conditions simulating those experienced in field deployment.

A laboratory measurement of the horizontal radiation pattern of the antenna was first made and is shown in Figure 9. This same

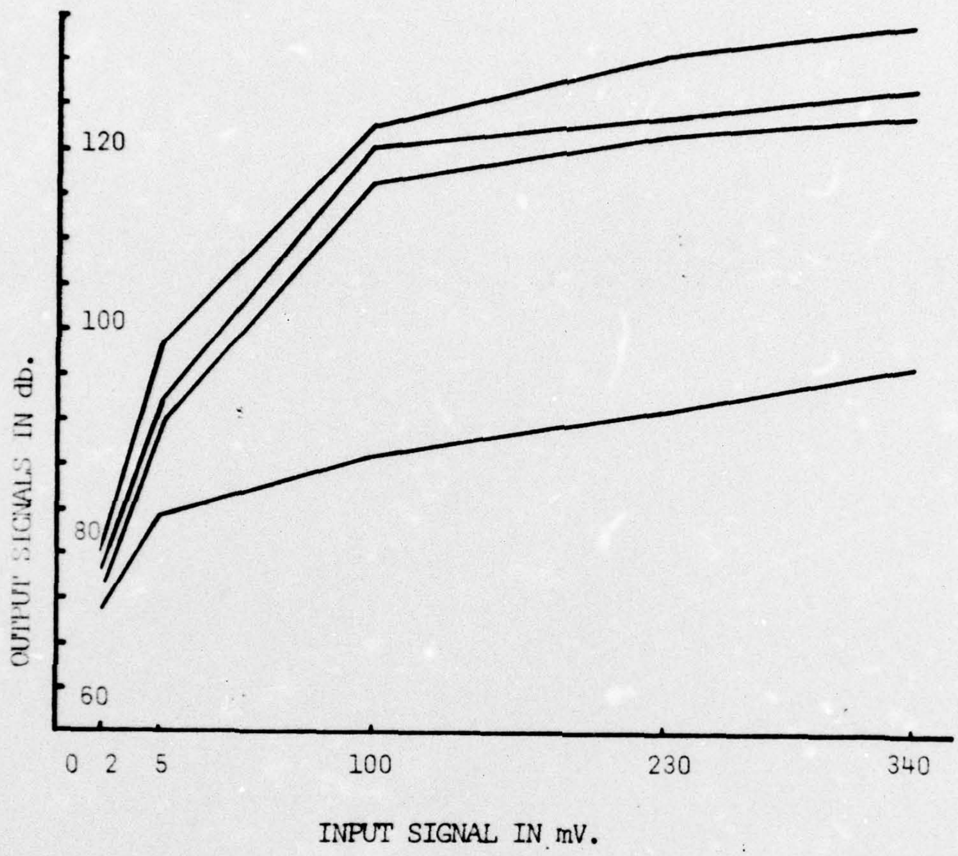


Figure 7. Comparative Radiation Efficiency of Four Helmet Antennas.

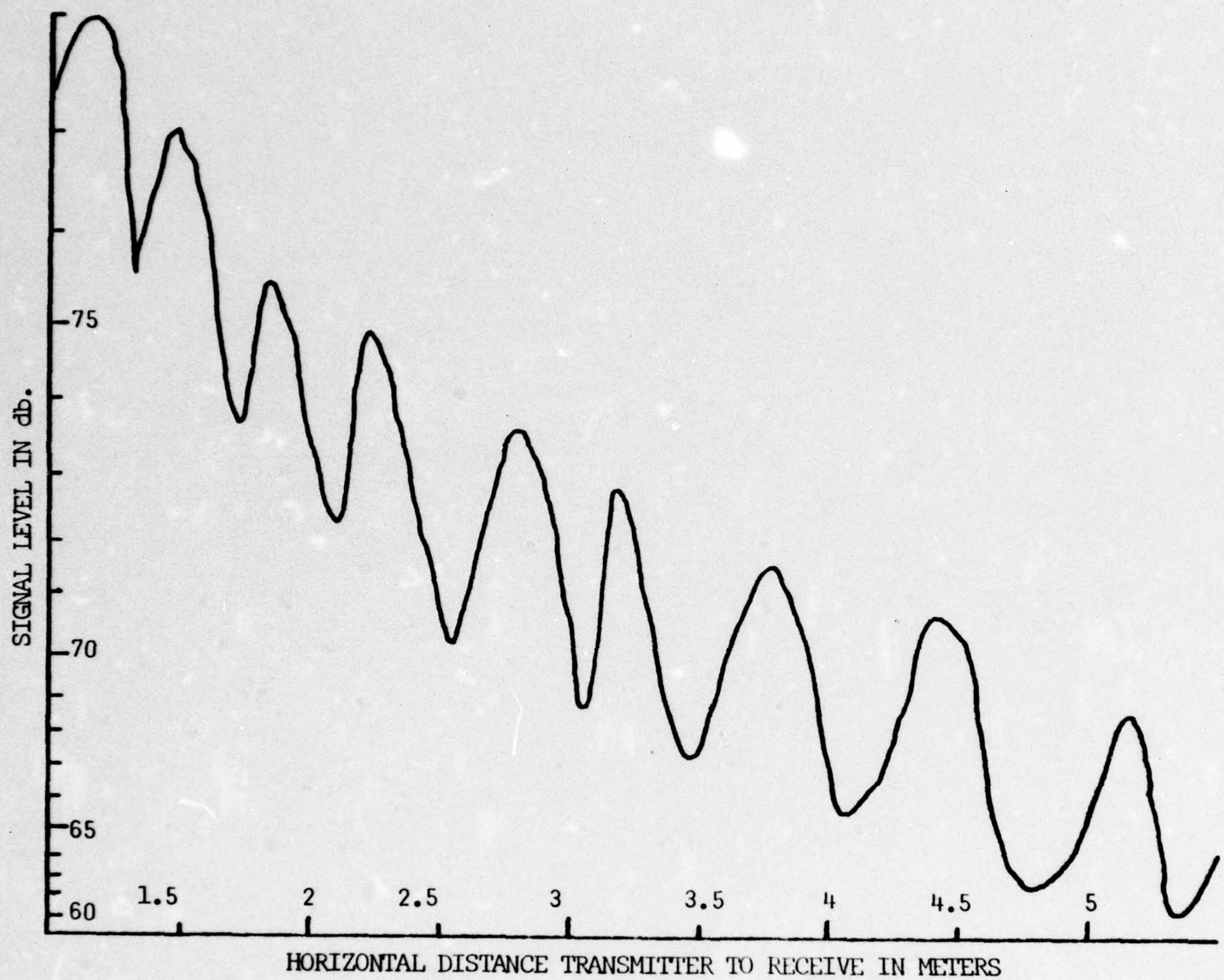
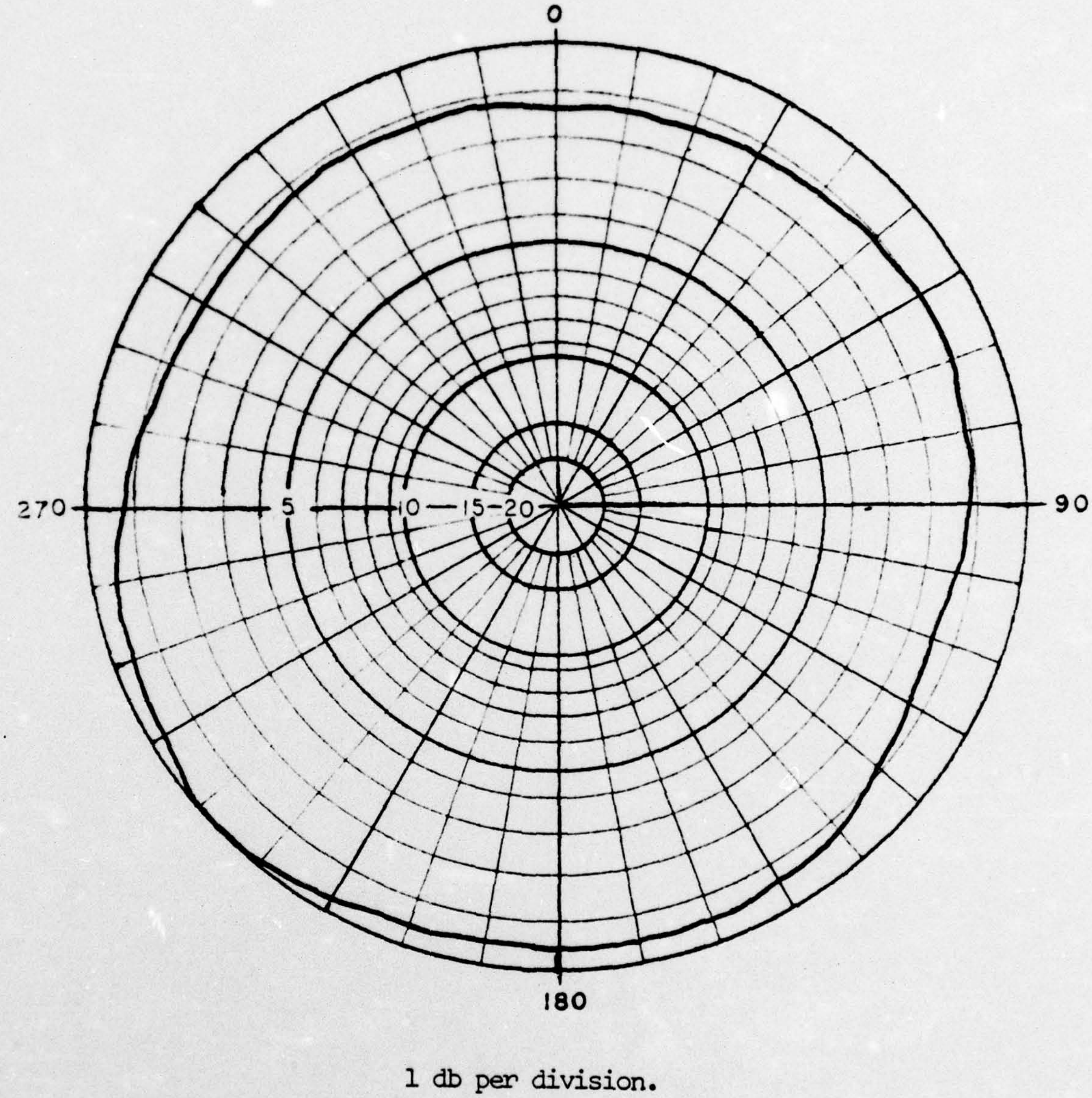


Figure 8. Helmet Antenna Null Pattern



1 db per division.

Figure 9. Helmet Antenna Radiation Pattern, Laboratory.

antenna, mounted on a helmet which was worn by an individual, was connected to a 918 MHz signal source by an 18 foot coaxial cable. A field intensity meter (AN/URM 17) and dipole antenna (AT 255), at a distance of 50 meters, was used as the test signal receiver.

An iron rod, used to simulate an M16 rifle, was held by the individual in three positions: (a) directly ahead at an angle of approximately 45 degrees, (b) against the left shoulder in a vertical position and, (c) directly in front in a horizontal position.

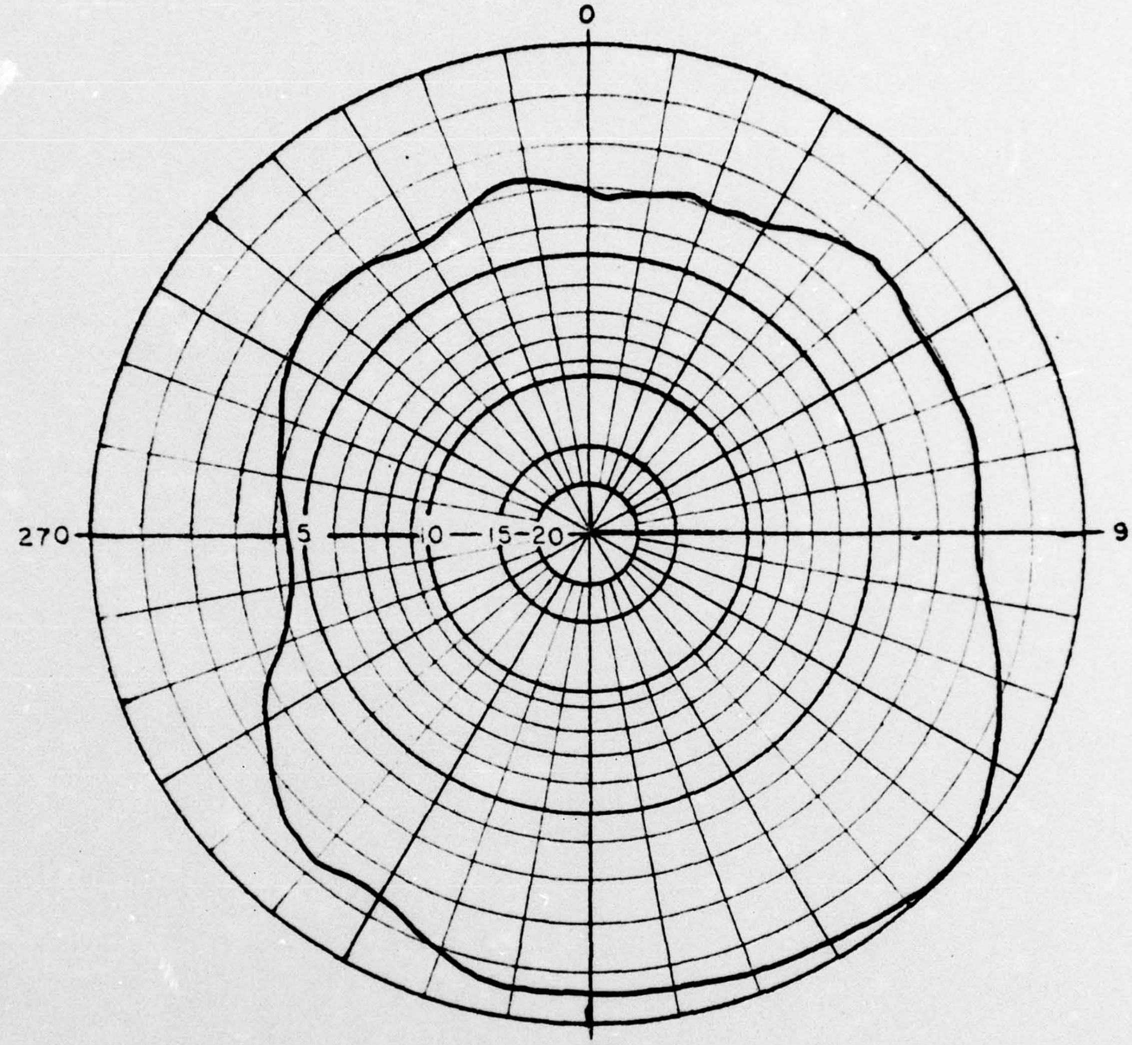
The individual, maintaining the simulated rifle in one of the three positions then turned, in 10 degree steps, and the corresponding signal intensity was recorded.

The simulated rifle, when held in the first position, appeared to have the most pronounced effect upon the horizontal radiation pattern exhibited (Figure 10). In each of the two other positions the horizontal radiation pattern of the antenna remained essentially unchanged from that observed in the previous laboratory observation.

Lastly, a test was conducted at the Hunter Liggett Military Reservation to evaluate the manner in which the posture and location of a soldier equipped with a B unit package might affect the radiation characteristics of the helmet antenna.

A helmet, with the antenna mounted, was simultaneously varied in height above ground (0, 1, 2 meters) location (unobstructed or behind a dirt embankment) and angle of inclination (0, 45, 90 degrees from vertical).

The antenna was connected to a signal generator set for a 918 MHz AM output. A receiver, located at a distance of 32 meters, was employed to record the test signal.



1 db per division.

Figure 10. Helmet Antenna Radiation Pattern, Field Test.

The results of these varied conditions upon the signal transmitted by the antenna are summarized in Table A1. The location of the soldier appears to have a significant influence upon the strength of the transmission of the B unit.

TABLE A1

Antenna Height/Location	Angle	Signal Level
2 meters above ground	00	0 db
" " "	45	- 1.3
" " "	90	- 8.2
1 meter above ground	00	- 2.0 db
" " "	45	- 2.3
" " "	90	- 9.2
Ground level, unobstructed	00	-11.4 db
" " "	45	-18.6
" " "	90	-23.3
Ground level, behind embankment	00	-13.2 db
" " " "	45	-20.0
" " " "	90	-23.9

2. The Vehicle Antenna

A two step procedure was carried out in order to analyze vehicle antenna performance. First, a single antenna was obtained and a measured horizontal radiation pattern was recorded.

The antenna, however, appeared to have been defective as the mast had been damaged and bent at a slight angle. The resulting radiation pattern exhibited extreme distortion from the normal omnidirectional pattern which would have been expected. This measurement was repeated several times with similar results.

The original intent of the experimental procedure was to have then mounted this same antenna, the radiation characteristics of which

had been established, on a vehicle and conduct similar measurements in the field to determine any variances due to the structure of the vehicle. However, since there was evidence that the antenna was defective, the two steps were conducted in reverse order.

A trial plan, involving measurement of radiation characteristics of an antenna mounted on an M60 tank was devised. The first step required that a single antenna, to be used for test purposes, be selected from the available inventory. A total of five antennas were presented. However, visual inspection revealed that four of the five exhibited noticeable damage. Defects included bent masts, patched holes in the sleeves covering the radiating elements, damaged connector threads and several other minor items. In view of the abnormal characteristics which had been exhibited by the first antenna tested in the laboratory, only the apparently undamaged antenna was employed for field measurements.

This antenna was mounted on an M60 tank, as shown in Figure 6 and connected to a signal generator (HP 612A). The signal generator was adjusted to supply a 50 per cent amplitude modulated signal at a frequency of 918 MHz. Signal level was set for 350 mV input and operating frequency was checked by a separate frequency counter.

A radio interference/field intensity meter (AN/URM 17) was used to record signal intensity. A standard dipole antenna (AT 255) was used to receive the signal and was mounted on a tripod at a height of seven feet.

The receiving antenna was stationed at a constant distance of 100 meters from the tank mounted antenna.

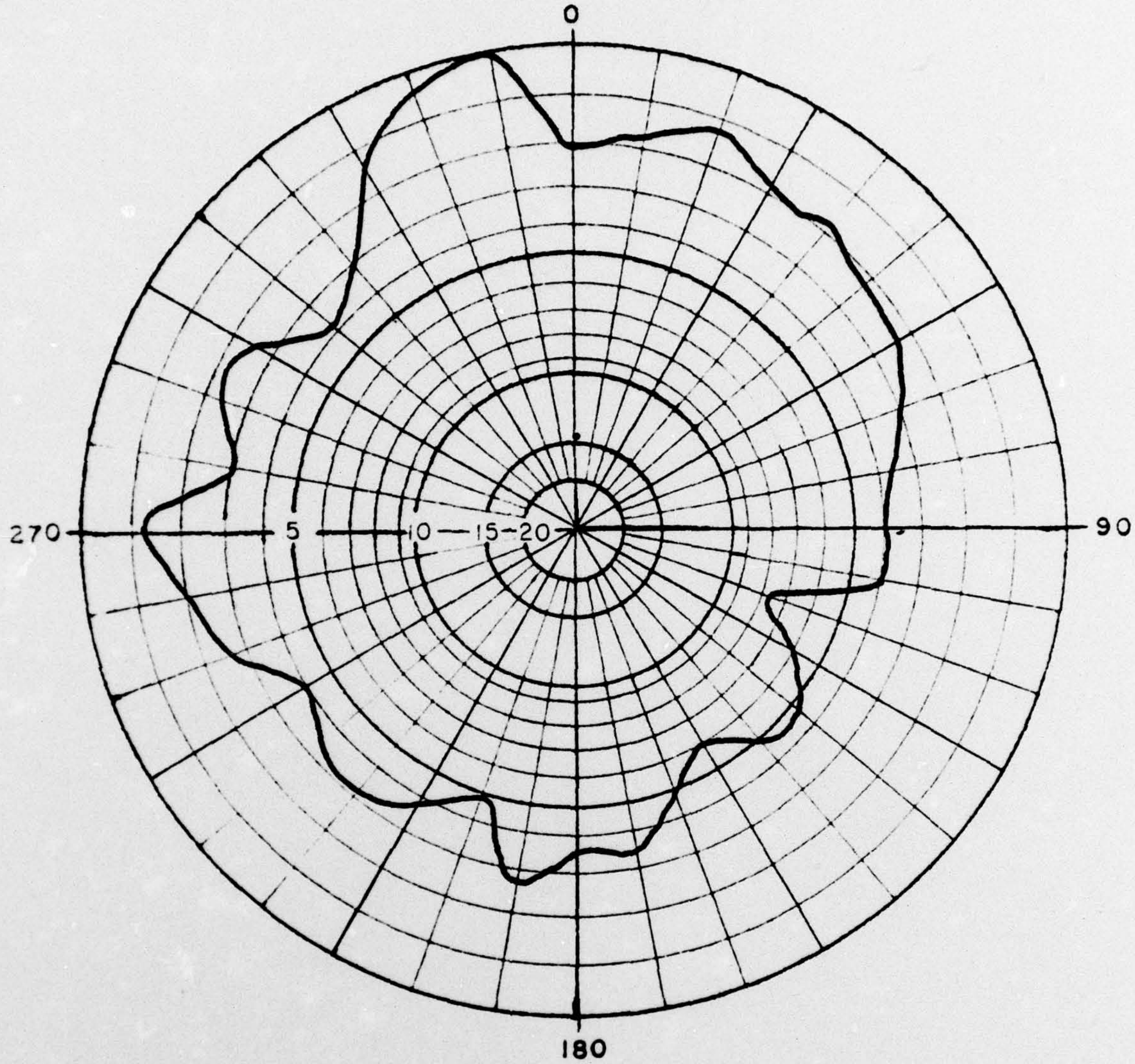
In order to obtain the horizontal radiation pattern of the tank mounted antenna, the tank itself rotated in a clockwise direction in ten degree steps through an entire circle. The tank driver, referring to a visual marker indicating the ten degree increments, then was able to reasonably approximate the exact angular positioning of the vehicle.

Throughout this first trial the gun barrel was fixed in train toward the rear of the tank. This position was chosen since it is the normal stowed location of the gun while the tank is moving.

The resulting measurement of the horizontal radiation pattern obtained for the antenna is shown in Figure 11. A brief series of measurements, with the tank moving in a counterclockwise direction, was taken to verify the location of the occurrence of maximum and minimum readings.

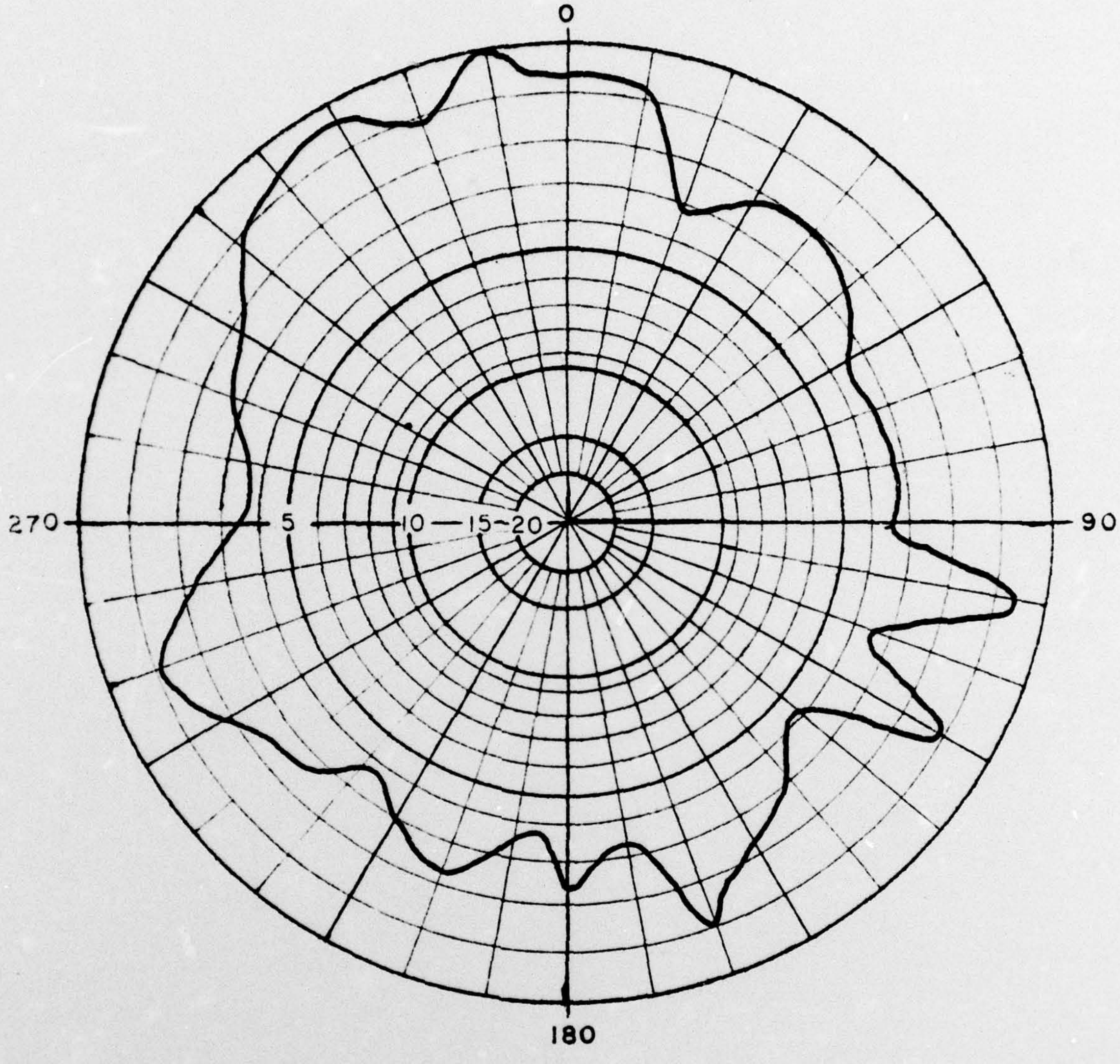
With the vehicle itself remaining stationary a third trial was performed by training the gun in a clockwise direction in similar ten degree steps and measuring the resulting horizontal radiation pattern of the antenna. Again, a short series of follow up measurements taken with the gun rotating in a reverse direction were recorded to recheck the positions at which maximum and minimum signals were noted. The resulting radiation pattern is illustrated in Figure 12.

A final series of trials was performed to examine the effects of other factors such as angle of inclination of the antenna. Since the vertically polarized antenna is mounted on a spring base and normally oscillates while the vehicle is in motion, the angular motion of the antenna results in variation in the strength of the transmitted signal. Signal intensity was observed to vary ± 4 db for the normal range of oscillation.



1 db per division.

Figure 11. Vehicle Antenna Radiation Pattern, Field Test, Tank Rotation.



1 db per division.

Figure 12. Vehicle Antenna Radiation Pattern, Field Test, Turret Rotation.

The effect of the elevation of the gun barrel on the received signal was also investigated. Readings of signal strength were recorded for angles of elevation ranging from minimum (approximately 10 degrees below horizontal) to maximum (approximately 20 degrees above horizontal). A peak variation of less than 2 db was noted.

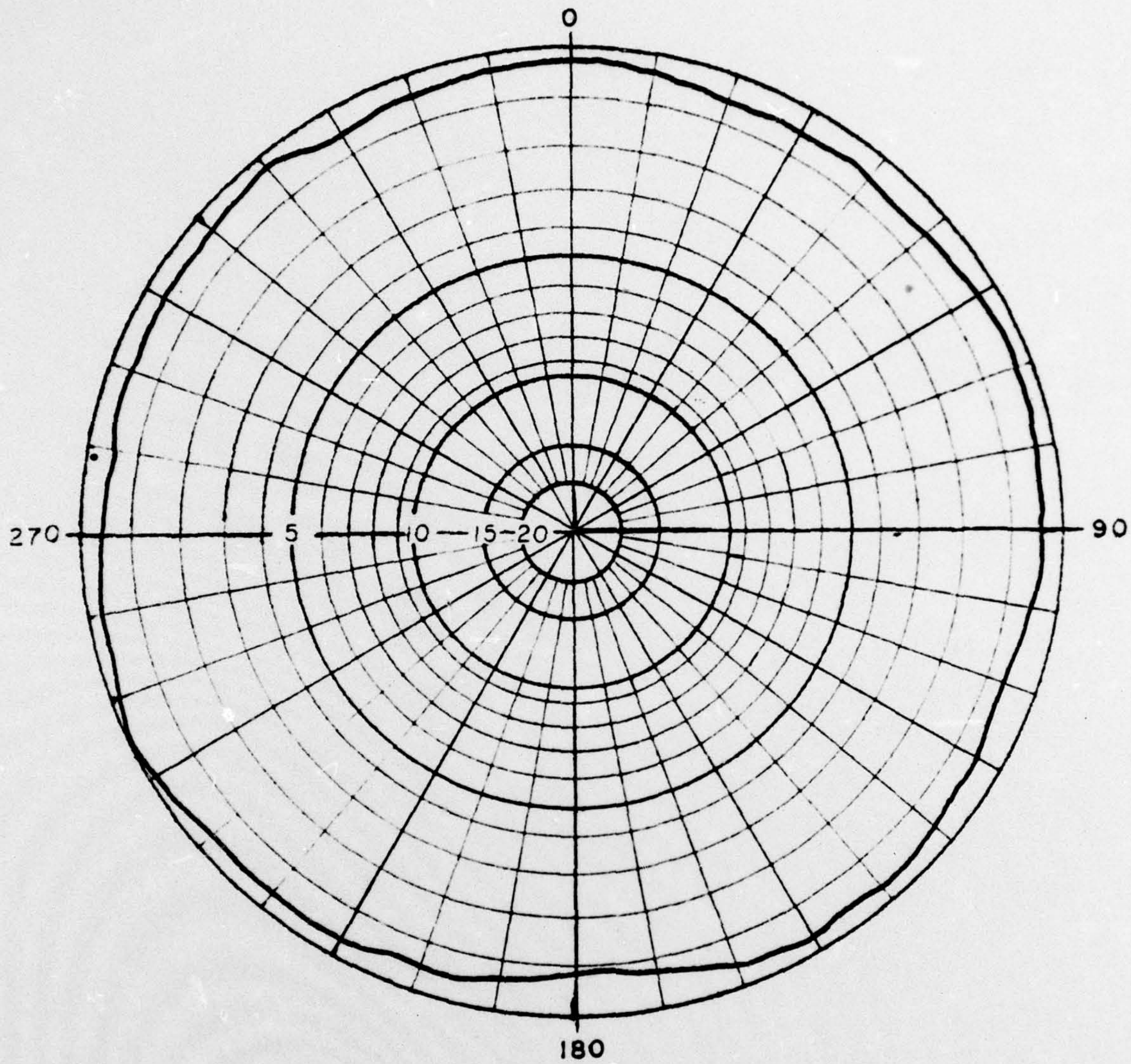
Throughout the field trials it was observed that any slight variation in the physical surroundings had an appreciable effect on the level of the received test signal. Opening and closing the access hatches atop the tank, oscillation of the communications antenna or movement of personnel or objects between the tank and receiver site each caused considerable variation in the intensity of the received signal.

As a last step, the vehicle antenna which was employed in the field trials was examined the following day under laboratory conditions. A horizontal radiation pattern of the antenna (Figure 13) was taken and repeated several times with similar results.

Differences in the antenna radiation characteristics were found to result from operation on the M60 tank. Distortions in both patterns measured in the field tests were similar and may have resulted from reflections from the vehicle surface or the communications antenna which was located at a distance of 1.24 meters from the RMS-2/ DCS antenna.

3. Summary of Test Results

Both the helmet and vehicle antennas, when tested under laboratory conditions with a theoretically infinite ground plane, exhibited omnidirectional radiation characteristics in the horizontal dimension. The maximum variation in signal level in the horizontal plane for the



1 db per division.

Figure 13. Vehicle Antenna Radiation Pattern, Laboratory.

helmet antenna was slightly greater than one decibel (Figure 9) and, for the vehicle antenna, less than one decibel (Figure 13). Thus, each antenna, for practical purposes, demonstrated nearly ideal omnidirectional radiation characteristics.

However, quite a significant departure from the omnidirectional characteristics of the vehicle antenna was found to result when the antenna was mounted on an M60 tank and tested. In this case, multiple reflections from the structure of the tank surface, including a second communications antenna located on the tank, appeared to account for major distortion of the radiation pattern. During the tests of the mounted antenna, variations in the horizontal radiation pattern were found to reach maximum values of 7.8 db (Figure 11) and 4.3 db (Figure 12) for two separate trials conducted.

The performance of the helmet antenna also varied over a wide range when tested under conditions which simulated those encountered in a field environment. By recording the level of the signal radiated by the antenna while it was located in a number of different positions (approximating the range of positions available to a soldier under conditions of simulated combat) the effects of antenna orientation and height above the ground were found to be significant.

Lastly, a number of antennas which were certified as suitable for use or deemed to be in good operating condition showed evidence of considerably decreased sensitivity. While the limited number of units involved would preclude any generalization concerning the entire inventory of antennas, the possibility that there are more defective antennas which have not been so identified exists.

If, in fact, various factors experienced in field operations significantly alter the antenna characteristics noted in the laboratory situation then, perhaps, such variation may partially account for the system outages experienced by RMS-2/ DCS.

V. CONCLUSION

In order that the current problems associated with RMS-2/ DCS may be viewed from a larger perspective, the development of position location and data collection systems employed by the U. S. Army Combat Developments Experimentation Command has been traced. From this summary it is evident that the present system represents a significant advance over previous techniques, despite the problems associated with the current installation.

A short description of RMS-2/ DCS was included as the framework necessary for understanding the scope of the difficulties experienced in the employment of the system.

Lastly, an attempt has been made to investigate certain aspects of RMS-2/ DCS by further defining two areas of potential problems which might contribute to decreased system reliability.

The issue of the existence of multipath propagation effects on system performance can only be answered in a general sense. The further question of the magnitude of such potential effects is extremely complex in nature. Variances in the terrain within the Hunter Liggett Military Reservation create a nearly impossible set of circumstances which must be considered in describing the multipath propagation problem.

The potential effects of the multipath propagation phenomenon have long been recognized; however, few of the difficulties experienced by RMS-2 DCS have been attributed to the operation of these effects.

The inescapable fact that some defective or marginal equipment will be fielded for use as well as the expectation of some number of failures during use creates a situation wherein the effects of multipath reflections may, in combination, strongly influence the reliability of RMS-2/ DCS during experimental trials involving the system.

From the evidence that is available, the extent of multipath propagation anomalies within certain areas covered by RMS-2/ DCS cannot be assumed to be so minimal as not to influence reliability of communication. Although the extent of the problem remains unclear, this phenomenon must be assumed to have some potentially negative effect, particularly in the case of marginal equipment.

Turning to the question of antenna performance, significant doubt about how well both the helmet and vehicle antennas perform in operation has existed. In order to obtain some basis for judgement a number of tests of both types of antennas was conducted. Evidence to indicate the existence of several antenna related problems was found.

Specifically, the antenna characteristics demonstrated under various operational conditions differ from those predicted by reference to performance documentation. While this in itself is not surprising, the range of variance, in some cases, may be great.

Whether such anomalies contribute to the majority of instances of RMS-2/ DCS link outages seems unlikely. But, when combined with the physical damage so easily incurred, the shortened useful life and the expense of replacement, an analysis to determine the feasibility of developing replacement antennas, an action already recommended by Scientific Support Laboratory personnel, is warranted. The following points should be examined, (a) alternate design possibilities, (b) additional performance specifications and, (c) comparative life cycle cost of a prospective replacement.

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